CORNING GLASS WORKS
ELECTRO-OPTICS DEPARTMENT
RALEIGH, NORTH CAROLINA

IMPROVED SCREEN FOR REAR-PROJECTION VIEWERS

Technical Report No. - 33
Date - October 11, 1968

PERIOD COVERED - September 13, 1968
to
October 11, 1968

ABSTRACT

Lenticular screens, conceptually, can achieve better performance than scattering particle type screens. Fabrication difficulties are the reason why lenticular screens are not widely used. Several screen concepts and some of the associated manufacturing techniques are discussed. The refractive index gradient scheme may well work but is equivalent in difficulty to fabrication of a 30 inch square fiber optic plate. Two crossed cylindrical lens schemes are discussed. One uses glass and the redraw process but entails difficulties in the fusing processes. The other uses plastic cylindrical lenses. Plastic diffraction grating provides a precedent that the plastic forming required is feasible. Masking difficulties and the optical design need further investigations.

A vacuum deposition technique is discussed. The potential here is that the lenticles are formed directly all over the screen simultaneously. The materials, process and masking required need further investigation.

TECHNICAL REPORT NO. 33

I. INTRODUCTION

Work performed prior to the current contract showed that improvements to screens based on scattering particles will at best be minor. It was also shown that efficiency, brightness variation and diffuse reflection are inter-related so that all these properties cannot be simultaneously idealized. Some work on lenticular screens was performed under the previous contract. One of the results of this work showed that lenticular schemes are not subject to the same limitations as scattering particle schemes. Conceptually, lenticular screens can simultaneously idealize many screen parameters. Fabrication difficulties are the reason why lenticular screens are not widely used.

II. Lenticular Screen Concepts

In order to approximate the favorable characteristics conceptually available, lenticular screens and their associated fabrication techniques are under investigation. Several conceptions have been formulated.

1. Refractive Index Gradient Scheme

Fiber-optic plates have been considered previously for screen use. Apart from the cost of large plates the light spreading characteristics were not satisfactory.

By changing the fibers to the variable refractive index form shown in Fig. 2 more control of light spreading can be achieved. Rays AA and BB show the normal action of the fiber in trapping and transmitting light incident on the core from within the trapping angle of the fiber. Exiting light will be spread by diffraction from the exit aperture of the core. The single entering direction of the rays is split into two exiting directions. Consideration of the square shape of the fibers shows that skew entering rays will be split into four exiting beams each of which will be spread by diffraction at the exit aperture. In fact the fibers become slightly diamond shaped during manufacture so that the exit rays form a hollow cone centered on the exit surface normal. The semi-angle of the cone is equal to the incident angle of the entering rays. All the exit rays are spread by diffraction. Consider light entering the cladding, ray CC'. This ray crosses the next core at a greater angle than the internal trapping angle and can traverse across the fibers freely. Partial reflection occurs at each core to cladding interface so that this light diffuses across the fibers. If the light exits a core as at C' the exit angle is determined by the combination of the incident angle and the trapping angle. If the light exits the cladding it is broadly spread by the narrow dimension of the cladding exit surface. These effects have been clearly demonstrated by using a laser to project a collimated beam of light through a number of different fiber optic plates. For use as a rear-projection screen light not trapped in the fibers reduces resolution so such light should be suppressed. For wide angle spreading the core size should be very small, perhaps 1 λ square. For the cladding to be effective in reflecting light a minimum thickness of one or two wavelengths is needed. Thus if cladding light is to be suppressed and wide angle spreading is needed, transmission efficiency (core area to total area) is low.

The variable refractive index approach offers considerable improvement over the simple fiber optic previously described. These elements are made with several concentric layers with decreasing refractive index from the central core to the outermost cladding.

Each layer acts as a cladding to the layers contained inside. Thus the light paths will typically be as for ray E. This entered in the N3 layer and propagates in the N1, N2 and N3 layers but not in the N4 layer. Considering E as a bundle, diffraction in the N3 layer causes different paths such as E′ and E″ to be followed. Reflection at the various interfaces causes paths such as F and G to be generated. The overall effect is that Bundle E is diffused through N1, N2 and N3 layers and exits in diffraction spread beams. Light entering N4 should be suppressed to maintain resolution with the result that the efficiency compared to the simple fiber optic screen is improved.

Fabrication of both types of fiber optic screen present comparable difficulties. In order to make a plate, a log of drawn fibers is formed. Suitable lengths of drawn fibers are laid side-by-side to fill a tool of the required cross-section and vacuum fused. Plates are then cut from the log. The minimum fiber length required for laying up is comparable to the longest dimension of the plate required. Thus for a 30 inch square screen about a cubic yard of fibers, weighing some 4,400 lbs. are required. Pulling this quantity of fibers and vacuum fusing present prohibitive problems. Once such a log is made many screens could be cut from it, given a suitable cutting machine. It can thus be seen that fabrication of such a screen in one piece, or even a few plates assembled together, presents prohibitive problems.

The performance should be good. Resolution is determined by fiber size. Antireflection coating both surfaces results in transmission (or absorption) of ambient light into the dark projector cavity. Efficiency should be greater than 50%. Color effects and angular light distribution would require detailed analysis if this approach were to be seriously considered.

2. Glass Crossed Cylindrical Lens Screen

Crossed circular cylindrical lenses approximate spherical lenses. To use crossed cylindrical lenses for screen elements the design must provide for ambient light transmission through or absorption by the screen and for satisfactory structural integrity. Lenticule size between 20 and 50 microns are required.

A scheme utilizing the glass redraw process has been devised. In this process cylinders of glass can be drawn longitudinally to reduce their cross-section. The shape of the initial cross-section is maintained through the process.

Figure 2 shows the starting cylindrical shapes. Individual components are contour ground to give the cross-section shown. The parts are then fitted together as shown prior to the first redraw. The rays AA′ and BB″ illustrate the intended operation when the lenticules are reduced to their final size. Projector light enters the low refractive index material N1 and is refracted at the interface with N2 where the light is focused at the lenticule exit aperture. Refraction at the N2 air interface will spread the light.

The first redraw fuses the assembly and reduces the size of the elements. The long thin strip of material produced by the first redraw is cut into smaller lengths and laid side-by-side with the low refractive index material in contact with a new substrate. The redraw and laying up operation is repeated as required to give the final sized lenticular cylindrical elements. The final redrawn strip is cut into lengths and laid up on a substrate the final size of the screen and fused. The result is a sheet with cylindrical lenticules with the masked side exposed. The process can be repeated but with the successive substrates fused to the masked side. A sheet with the low refractive lenticule material exposed is the result. The two final sheets are fused together with cylindrical lenticules adjacent and crossed. Finally both exposed sides should be antireflection coated.

Probably the prime outstanding difficulty with the proposed process is the laying up and fusing after each redraw. Gaps between adjacent strips should be appreciably smaller than one lenticule if they are not to be visible.

Performance should be good. The distribution of light within the viewing angle can be controlled by the exact shape of the cylindrical lenticules used. Different distributions in vertical and horizontal directions can be provided. Most of the projector light passes through to the viewer side resulting in high efficiency. Very little ambient light will be reflected back towards the viewer - most light evading the absorbing glass will pass through the screen towards the projector. The screen has the structural integrity of a sheet of glass.

3. Plastic Crossed Cylindrical Lens Screen.

Figure 3 shows a crossed cylindrical lens screen using plastic lenses. The lens shape could be rolled or embossed into a thin plastic sheet. 100 feet long plastic sheets of 8½" wide diffraction grating at 2 microns pitch can be purchased inexpensively indicating that formation of cylindrical lenticules of 20 microns pitch should be feasible. The masking could be formed by application of a negative photoresist to the flat side of the plastic sheet and exposing the resist through the cylindrical lenticules. After processing, the masked plastic sheet is mounted on a glass substrate using an adhesive. Particular care is needed to prevent bubbles in the adhesive layer.

A crossed set of cylindrical lenticules is mounted on the second side of the glass substrate as in the Figure.

Since the projector light illuminates all regions of the second set of lenticules no masking is provided. Antireflection coatings deposited at low temperature on the outside surfaces will maximize screen efficiency. Specular reflection does not occur with this screen design.

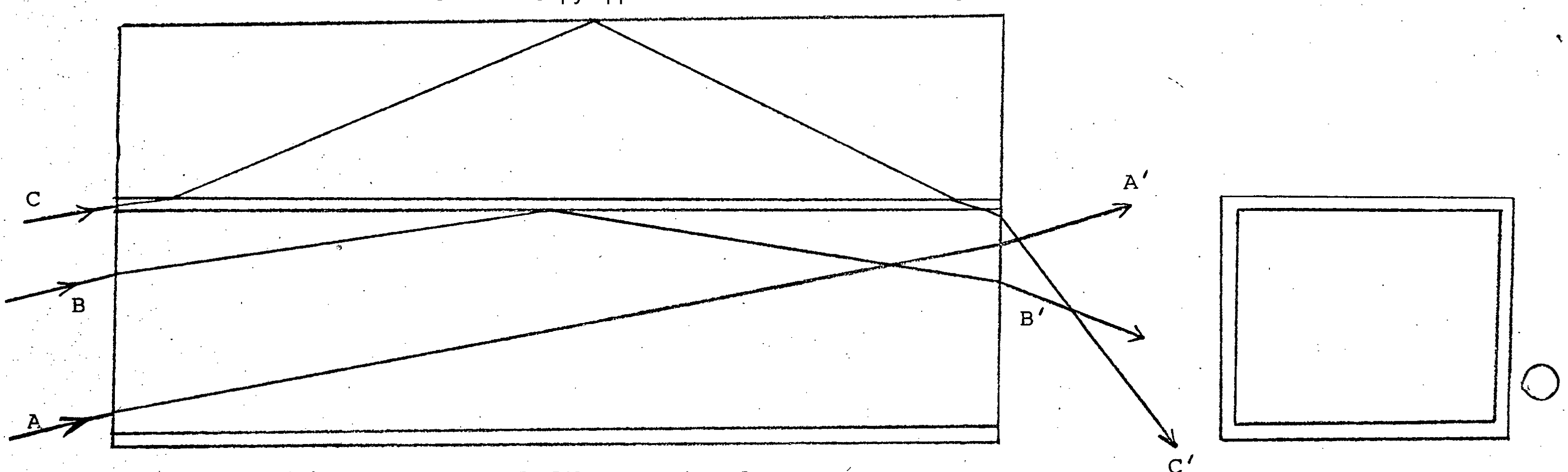
Performance is good, being comparable to the glass cylindrical lens scheme. The effects of spreading the projector light in different directions from slightly different spreading planes need careful evaluation if this scheme is to be examined further.

4. Vacuum Deposition Techniques

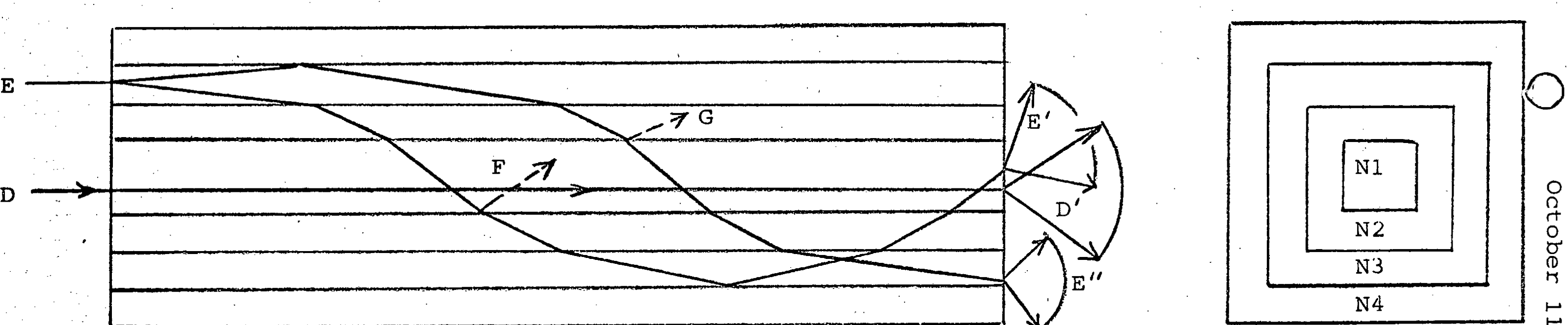
The possibility exists of using vacuum deposition techniques to form lenticules directly and all over the screen simultaneously. Lenticular lenses could be formed by depositing transparent material onto glass through an evaporation mask. For example, Buckbee-Mears Co. advertise accurate mesh screens with four million holes per square inch.

After material deposition, raising the substrate temperature could allow surface tension to form the deposited material into approximately spherical lenslets. Masking might be provided by a deposition of optically absorbing material prior to depositing the lens material. By placing the absorbing material source well off the axis of the screen and rotating the source about the screen axis, an absorbing ring for each lenticule can be deposited. The lens material would be deposited on top of the mask material from a source on the screen axis using the same evaporation mask.

This type of approach, where all the elements are formed simultaneously, is potentially economical. The performance to be expected depends greatly on the detailed arrangements actually used to make screens.



1 (a) Conventional fiber optic element



1 (b) Variable refractive index element

Figure 1. Variable refractive index element.

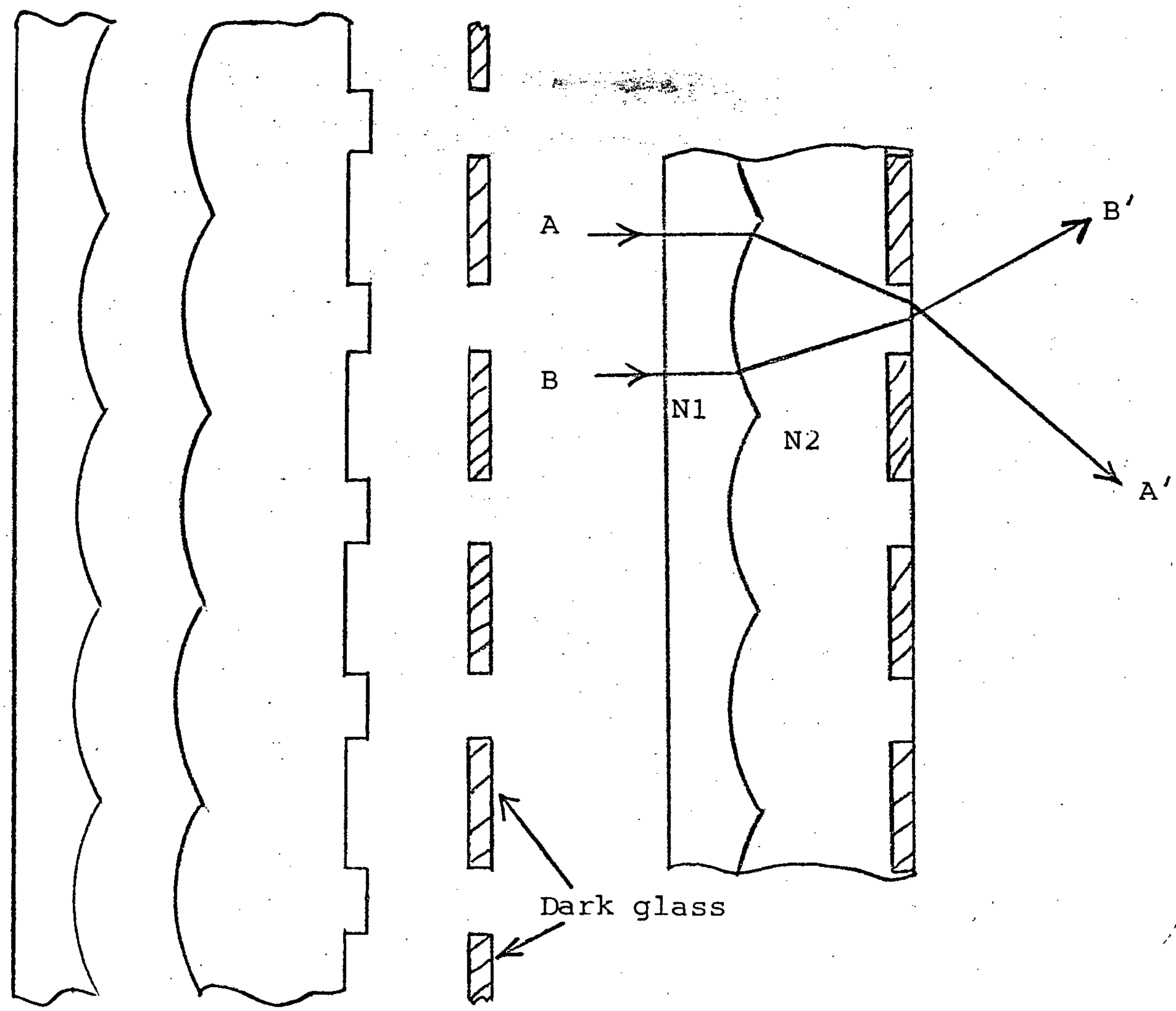


Figure 2. Initial parts and assembly.

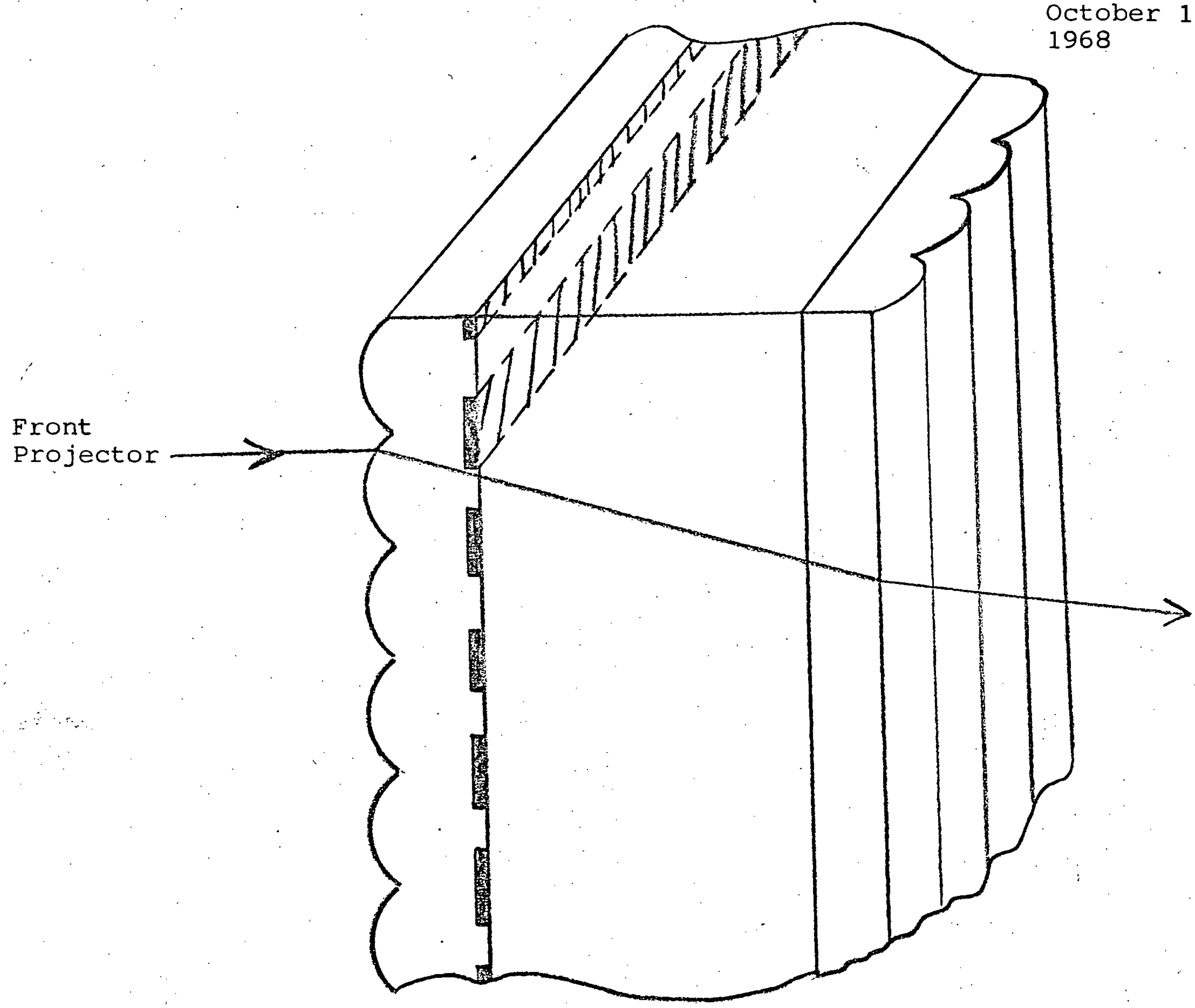


Figure 3. Plastic crossed cylindrical lens screen.